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**ATTENTION AND DECISION FACTORS  
IN BIMODAL SIGNAL PROCESSING**

Dr. M.L. Shaw

Rutgers - The State University of New Jersey

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  → The research to be described is directed toward answering two related questions: (1) how is information from multiple sensory sources combined to reach a binary "yes-no" detection decision, and (2) does dividing attention among multiple sources cause losses of information. During this first year, efforts have focused on examining information integration and attention allocation with simple unimodal stimuli. Three experiments were run to investigate the first question when sources of information were		

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cont → defined as different hypothetical frequency channels and the stimuli were simple tones. Data from these studies indicated that separate decisions are formed about the presence of a tone in each channel, and these independent decisions are then pooled to arrive at a "yes-no" response. This independent decisions model was supported both for widely separated tones and for tones differing in frequency by only one tenth of a critical band (e.g., 700 and 715 Hz). The data rejected the idea that representations of the sources are integrated prior to making a decision, an apparent contradiction to previous conclusions about information integration in auditory detection.

→ With regard to the second research question, a pair of experiments showed that losses of information apparently do not result when the number of hypothetical frequency channels is increased from two to four. This result suggests that attention to pitch is not capacity limited. A final group of experiments, using visual stimuli, indicated that dividing attention among display locations does cause losses of information when the task requires pattern analysis (letter detection), but that such losses do <sup>not</sup> occur when only a simple luminance increment detection is required.

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**MATTHEW J. KEEPER**

Chief, Technical Information Division

**A. Introduction**

The purpose of our research program is to study the consequences of dividing attention between modalities (auditory and visual) and among different sources of information within modality. The planned research is directed toward answering two related questions: (1) how is information from multiple sensory sources combined to reach a binary "yes-no" detection decision; and (2) does dividing attention among multiple sources cause losses of information. We are attempting to answer these questions for stimuli varying in input modality and in complexity (simple brightness and loudness increments versus more complex patterned stimuli). In each case, subjects are presented with near threshold (or above threshold, limited exposure) stimuli embedded in noise. On each trial of a typical experiment, subjects are required to make two responses -- a "yes-no" detection decision and a forced-choice judgment of the target's location, modality, or some other appropriate stimulus dimension.

The framework for the proposed research is based on earlier theoretical work (Shaw, 1980) and on the results of two prior studies using bimodal stimuli (Mulligan & Shaw, 1980; 1981). In the first of these studies the stimulus on each trial was either a light flash, a tone burst, or both of these together. It was shown that subjects arrive at their "yes-no" response by combining separate decisions made about each source of sensory information. If at least one decision is positive, i.e., either a light or a tone is detected, the subject responds "yes". Predictions of this model were tested against predictions of a number of other models, including the integration model of signal detection theory which says that subjects integrate information to form a decision variable, and then compare this variable to a decision criterion. All of the alternative models were rejected.

The second experiment examined the effects of dividing attention between vision and hearing in a two-location, forced-choice task. The results indicated that, with simple light and tone signals, no information losses are evident when attention must be divided between modalities as compared to a condition in which attention may be focused on a single modality. Our interpretation of these results depends critically on the assumption that the dimensions we choose to vary within modalities (spatial location for both modalities in this experiment) are indeed those for which dividing attention results in a loss of information. While we have support for this assumption for letter stimuli, the empirical evidence for simple lights and tones is equivocal. In order to test this assumption, it is necessary first to have a better understanding of the consequences of dividing attention between stimulus sources within a single modality. In particular one would like to know, for the different attributes which might be used to define independent sources of information within a modality (e.g., location versus pitch for auditory stimuli), whether or not increasing the number of

to-be-attended sources (locations or pitches) results in losses of information.

The general objective for the first year of the grant, then, was to learn more about information aggregation and attention allocation among sources of information within a modality. This prerequisite information will then be used in helping to design studies to investigate the effects of dividing attention between modalities, and to interpret their results. Several specific questions had to be answered before proceeding to the bimodal studies:

(1) How is information combined (i.e., what decision rule is applied) when subjects must divide their attention between two (or more) auditory sources in a detection task? Does the same decision model apply when the sources are tones in different hypothetical frequency channels as when the sources are defined as different locations in auditory space?

(2) Does increasing the number of to-be-attended sources cause losses of information? Does this result differ when the sources are defined as spatial locations as opposed to when they are defined in terms of frequency channels?

(3) For the visual modality, do losses of information result when attention is divided among several locations in a simple luminance increment detection task?

The experiments described below were carried out to investigate these and other questions regarding dividing attention within a modality.

## B. Status of the Research Effort

Much of our effort during the first six months was devoted to setting up our microcomputer-controlled laboratory, and developing software to control auditory and visual psychophysical, decision making, and attention experiments. A total of five experiments were completed during this year, with a sixth in progress.

### 1. Studies of Information Integration

In our earlier bimodal experiments, auditory information sources, like visual sources, were distinguishable by their different spatial locations. There is some evidence, however, that the frequency dimension may be a more appropriate auditory analog to location in visual space. To investigate this question, we designed a series of experiments examining information integration and attention allocation in two situations -- one in which auditory sources are defined in terms of hypothetical frequency channels, and a second in which the sources are locations in auditory space. The first experiment examined how information is pooled across frequency channels in a simple tone detection task. The data indicate that although there may be individual differences in how attention is allocated among pitches, all subjects appear to use a decision rule in which independent binary categorizations of the information in each channel are summed at the decision stage of processing. This same

independent decisions model best accounted for information integration across modalities (Mulligan & Shaw, 1980) and across target locations in a visual letter detection task (Shaw, 1982). We were able to reject several alternative models, including an energy summation model in which sensory representations are summed (Weighted Integration model) instead of decisions about sensory representations (as in the Independent Decisions model).

The independent decisions model was supported even for one condition in which the two tone stimuli (the two information sources) were within the same critical band. Rejection of the energy summation model in this condition is a surprising contradiction to previous conclusions about information integration in auditory detection. This result also indicated that the hypothesized frequency channels may not, contrary to our original conception, be based on critical bands. To further explore this result, a second detection experiment was done in which the frequency separation of the tone pairs was systematically varied in terms of percent of critical bands. For all conditions (base frequencies 470, 1500, and 3100 Hz and frequency separations ranging from approximately 0.10 to 10.0 critical bandwidths) subjects once again combined information across frequencies according to the independent decisions model.

A third experiment was run using a subset of the stimuli from the previous study as well as some additional tone pairs having very small frequency differences (approximately 0.02 critical bandwidth; equal to 3 Hz for a 700 Hz tone). The small frequency separations correspond to those used by Hall and Sondhi (1977), whose data support an energy summation model. In addition to the new stimuli, this experiment differed from the previous two in that subjects made only a "yes-no" detection response and not the additional tone identification response. It was suspected that the forced-choice tone identification response required in the previous studies may have biased subjects toward adopting an independent decisions strategy. This suspicion proved unfounded, however, since again most of the data were best fit by the independent decisions model. Even with the very closely spaced tones, only one of four subjects showed any reliable evidence of using energy summation. Data on the near frequency pairs for the other three subjects either fit the independent decisions model or rejected all the models tested. Other possible models, such as the maximum likelihood model, are being considered. Interpretation of the near frequency conditions is further complicated, however, by the "beats" (amplitude modulation which occurs at a frequency equal to the difference frequency of the two tones played simultaneously) which occur with these stimuli.

Apart from the very-near-frequency conditions, the following conclusions can be drawn about combining information from two auditory sources or channels where these channels are defined in terms of stimulus frequency:

- (1) Information from two hypothetical frequency channels is combined in a detection task by pooling the results of separate

binary decisions about the presence of a signal in each channel; if either of these decisions is positive, the subject responds "yes". This independent decisions rule obtains both for widely separated tones and for tones differing in frequency by as little as one tenth of a critical band.

(2) These results are obtained both when subjects are encouraged to process the frequencies separately by requiring a tone identification response in addition to the "yes-no" task, and when no such frequency specific response is required.

(3) The notion of energy summation for stimuli falling within the same critical band is not a meaningful one for this type of detection task. Other results explained in terms of energy summation within a critical band must be reconsidered.

## 2. Studies of Divided Attention

Does increasing the number of to-be-attended sources of information result in a decrease in the amount or quality of information obtained from each source? Previous studies have revealed that this question is answered in the affirmative when the sources are locations on a CRT in a target letter detection and localization task. The answer is "no" however, when the sources are input modalities and the stimuli are simple energy increments. In the following experiment we sought to answer the above question for the case in which sources of information are different hypothetical frequency channels in the auditory system.

The task was a forced-choice pitch identification with either two or four possible stimulus pitches in a given block of trials. The drop in performance from set size two (2 possible frequencies) to set size four (4 possible frequencies) was compared to that predicted by several models. Analysis of our results indicated that the observed drop in identification performance could be accounted for entirely by decision selectivity, i.e., by the increased probability of mistaking noise for signal with increasing set size.

Interpretation of this data is complicated, however, by a strong "anchor" effect in the categorization of pitches. In order to make the tones equally discriminable in our four tone condition, we had to make the middle pair of tones much further apart in pitch units than the end pairs of tones. To circumvent this categorization problem, a similar set size experiment is now in progress using a two-interval, forced-choice task rather than identification. This study is nearing completion and preliminary analysis of the data indicates that the conclusions of the previous study will hold up, i.e., dividing attention among frequency channels does not produce losses of information.

There has been considerable disagreement in the literature over whether or not processing of simple light flashes at different locations in the visual field is capacity limited. Using the same paradigm with which we successfully demonstrated that dividing attention does cause losses of information when

complex pattern analysis is required (letter detection task), we have recently shown that such losses do not occur when simple luminance increment detection is required. An advantage of this study over others dealing with this problem is that it separates the contribution of the decision stage from that of the coding stages of processing in analyzing the drop in performance with increasing set size.

3. Research Plan for June 1982 - June 1983.

In the early part of our second year of funding we will finish laying the necessary groundwork for our investigation of bimodal processing. A group of experiments comparable to those in which sources of information were defined as auditory frequency channels are planned with the which information sources now defined as locations in auditory space. A pedestal-increment tone identification paradigm will be used in another experiment in an attempt to verify our unexpected finding of no loss if information when attention is divided among frequency channels. After completing the single modality experiments, we will focus for the remainder of the year on several of the proposed bimodal experiments.

C. MANUSCRIPTS IN PREPARATION

1. Shaw, M.L. Consequences for coding variability of the spatial distribution of attention: A fundamental difference between pattern and luminance detection. To appear in Attention & Performance X.
2. Mulligan, R.M. & Shaw, M.L. Information integration in auditory detection: Combining information from hypothetical frequency channels. To be submitted to Perception & Psychophysics.
3. Shaw, M.L. & Mulligan, R.M. Dividing attention among hypothetical frequency channels. To be submitted to Perception & Psychophysics.

D. PROFESSIONAL PERSONNEL

1. Dr. Marilyn L. Shaw, Principle Investigator
2. Dr. Robert M. Mulligan, Research Associate

E. PAPERS PRESENTED

1. Shaw, M.L. Consequences for Coding Variability of the Spatial Distribution of Attention: A Fundamental Difference Between Pattern and Luminance Detection. Invited paper given at the Tenth Annual Symposium on Attention and Performance, Venlo, The Netherlands, July 1982.
2. Mulligan, R.M. Information Integration in Auditory Detection. To be presented at the annual meeting of The Psychonomic Society, Minneapolis, Minn., November 1982.
3. Shaw, M.L. Consequences for Coding Precision of the Spatial Distribution of Attention. To be presented at the annual meeting of The Psychonomic Society, Minneapolis, Minn., November 1982.

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